# CHAPTER 2

# FUNCTIONAL DESIGN

## 2-1. Design Overview.

### a. General.

(1) The selection and the evaluation of site conditions and hydraulic factors are necessary for the functional planning of the structure and the selection of design conditions. Because of local site conditions, it may be impractical to evaluate alternative structure types. For example, foundation conditions may eliminate a gravity structure, the size and location of the area to be protected may dictate the orientation and shape of the structure, or the longshore transport rate may necessitate supplementary structures to minimize channel maintenance and control adverse effects on adjacent shores. The design reports should provide sufficient information to justify the recommended design and adequate presentation of alternatives to assure that all practical structural and nonstructural options were considered. Design memoranda should include the formulas used, the assumptions made, and the evaluation of coefficients, so the reviewer can check any particular computation needed to verify the design. Refraction and diffraction diagrams should be included in the design memoranda. Deviation from or modification of accepted practices should be explained and substantiated. The design memoranda will include also an evaluation of the environmental aspects of the recommended plan and each of the alternatives.

(2) The cost of construction is generally a controlling factor in determining the type of structure to be used. A limited number of types of construction will be practical in any locality; but the cost of constructing and maintaining the different types may vary considerably, and the final decisions in design will be dictated by either the initial cost of the structure or the annual costs. A comparison should be made on the basis of annual cost which includes the interest, amortization, and maintenance. Comparative designs of several types with estimates of annual costs are necessary before final decisions can be made. Annual costs of maintaining the navigation channel and other associated costs, such as any costs incurred by the mitigation of anticipated unwanted effects on adjacent shores, are items for consideration.

(3) The quantities of material required for breakwater or jetty construction usually are large, and considerable savings in transportation cost may be achieved if suitable materials can be obtained locally. The selection of a rubble-mound-type structure is generally dependent upon the availability of a large amount of suitable stone at low cost, and the use of concrete will be affected by the availability of quality aggregates.

(4) The average annual cost of maintenance is often a significant portion of the total annual cost of a project. However, a structure designed to resist the action or stresses of moderate storms, but which may suffer some

damage without complete destruction in a severe storm, may show a lower total annual cost than a structure designed to be completely stable for all storms. The lowest annual cost should be determined by considering the annual cost for increments of stability.

b. Design Verification. The formulas and design charts presented in this manual can be used in the preliminary design to screen alternatives. Existing long-term prototype data and/or prototype tests can also be a part of design verification. However, final designs may require verification by hydraulic model testing. Model tests can evaluate armor stability, wave runup and transmission, and potential effects on adjacent shorelines.

c. Monitoring. Development of a monitoring plan should be included as a part of the project design. The plan can include periodic surveys and inspections, comparison of survey results with design predictions, and comparison of actual maintenance costs with predicted maintenance costs.

2-2. Design Studies. The design of breakwaters and jetties requires an understanding of the problem, assembly and evaluation of all pertinent facts, and development of a rational plan. The design engineer is responsible for developing the design rationale and sufficient alternative plans so that the economically optimum plan is evident and the recommended plan is substantiated. Applicable Corps of Engineers (Corps) guidance should be considered in the design. Pertinent textbooks, research reports, technical reports, and expertise from other agencies may be used as source information. The steps leading to a sound plan are outlined as follows:

a. Review appropriate Engineer Regulations, Manuals, and Technical Letters and other published information.

b. Assemble and analyze pertinent factors and environmental data.

c. Conduct baseline surveys.

d. Select a rational set of design conditions.

e. Develop several alternative layouts with annual costs

f. Develop an operation and maintenance plan.

g. Select an economically optimum plan.

h. Assess environmental and other impacts.

i. Develop a recommended plan.

2-3. Typical Engineering Studies. The following kinds of studies are normally undertaken for breakwater and jetty design:

a. Water levels and datums.

b. Winds.

c. Waves.

d. Currents.

e. Geotechnical considerations.

f. Construction materials and sources.

g. Ice conditions.

h. Shoreline changes.

i. Prior projects and their effects.

j. Baseline surveys.

k. Constructability.

l. Design life, degree of protection, and design conditions.

m. Dredging and disposal.

n. Seismic design.

o. Vessel impact.

p. Environmental impact.

q. Model tests.

r. Operation and maintenance.

2-4. Water Levels and Datums. Both maximum and minimum water levels are needed for the designing of breakwaters and jetties. Water levels can be affected by storm surges, seiches, river discharges, natural lake fluctuations, reservoir storage limits, and ocean tides. High-water levels are used to estimate maximum depth-limited breaking wave heights and to determine crown elevations. Low-water levels are generally needed for toe design.

a. Tide Predictions. The National Ocean Service (NOS) publishes tide height predictions and tide ranges. Figure 2-1 shows spring tide ranges for the continental United States. Published tide predictions are sufficient for most project designs; however, prototype observations may be required in some instances.

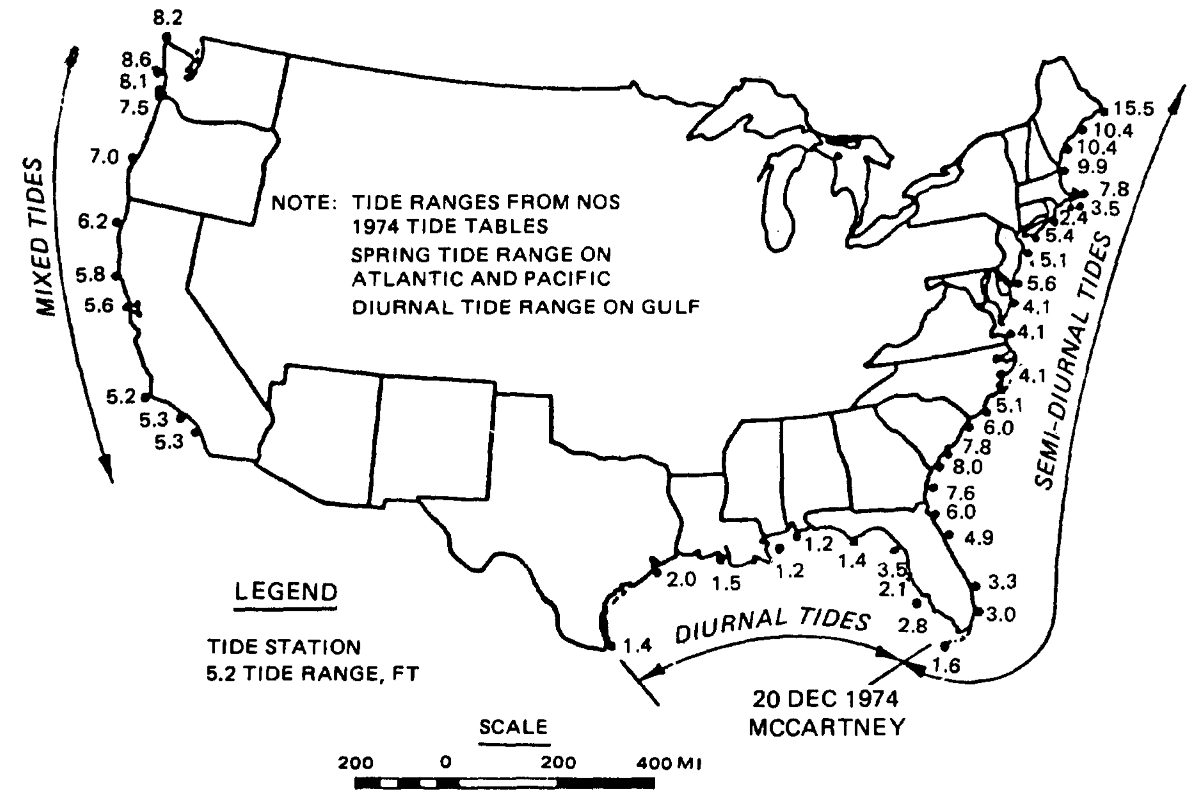


Figure 2-1. Ocean tide ranges for the continental United States

b. Datum Planes. Structural features should be referred to appropriate low-water datum planes. The relationship of low-water datum to the National Geodetic Vertical Datum (NGVD) will be needed for vertical control of construction. The low-water datum for the Atlantic and Gulf Coasts is being converted to mean lower low water (MLLW). Until the conversion is complete, the use of mean low water (MLW) for the Atlantic and Gulf Coast low water datum (GCLWD) is acceptable. Other low-water datums are as follows:

Pacific Coast: Mean lower low water (MLLW)

Great Lakes: International Great Lakes Datum (IGLD)

Rivers: River, low-water datum planes (local)

Reservoirs: Recreation pool levels

2-5. Waves. Naturally occurring wind waves and vessel-generated waves require analysis and prediction. Wave conditions are needed for various elements of the project design.

a. Wind Waves. Prediction of wind wave heights and periods can be made using techniques presented in item 132. Wave information based on numerical hindcasts for some coastal waters and the Great Lakes has been published by the US Army Engineer Waterways Experiment Station (WES) (items 39, 40, 41, 111, 112, 113, 114, and 115). These wave heights and periods are applicable for deep water and require refraction and diffraction analysis to develop wave characteristics at the project site. Chapter 2, item 132, presents a method for calculating refraction and diffraction effects. If feasible, installation of wind and wave gages at the project site is strongly recommended. One year of wind and wave records is considered a minimum to verify or adjust wave predictions before the design is made final.

b. Vessel-Generated Waves. Passing vessels may generate larger waves than the wind. This is particularly true for small boat harbors. The height of waves generated by a moving vessel is dependent on the following:

(1) Vessel speed.

(2) Vessel draft and hull shape.

(3) Water depth.

(4) Blockage ratio of ship-to-channel cross section.

The effects of waves will depend on the height of the wave generated and the distance between the ship and the project site. An estimate of the height of a ship-generated wave can be obtained by assuming that the wave height (crest to trough) will be equal to twice the amount of vessel squat. The wave height at the shore is then computed using refraction and diffraction techniques. The wavelength is equal to approximately one-third of the vessel length. If vessel-generated waves are considered the design wave, model tests or prototype measurements will be needed to verify or adjust the predictions.

c. Tsunami Waves. Tsunami waves can usually be predicted with sufficient accuracy by performing a statistical extrapolation of historical data. However, when the primary purpose of a structure is protection against tsunami waves, it may be necessary to numerically study tsunami generation, propagation, and amplification, and then to apply the results of the study in a physical model to determine tsunami/structure interaction and stability.

d. Selection of Test Waves from Prototype Data. Measured prototype wave data on which a comprehensive statistical analysis of wave conditions can be based are usually unavailable for various project areas. However, statistical or deepwater wave data representative of these areas can sometimes be obtained and transposed to the site by refraction and diffraction calculations. Sources of prototype wave data for the Atlantic, Gulf, and Pacific Coasts are items 11, 41, 84, 85, 94, 100, 136, and 137. Wave data commonly used for study sites on the Great Lakes can be obtained from items 5, 11, 35, 111, 112, 113, 114, 115, and 127.

2-6. Currents. Currents can be tidal, river, wind, or seiche induced. Prediction of current strength and duration is needed for the selection of design conditions. Current forces and flow velocities are considered in the designing of rubble-mound toes and floating breakwater mooring systems.

2-7. Geotechnical Considerations. The selection of the type of breakwater and jetty structure as well as the configuration is significantly influenced by geotechnical and site conditions. Foundation conditions at a site may range from solid rock to soft mud, and each foundation condition requires different design considerations. Geotechnical studies for a project should include adequate subsurface investigations, laboratory testing, and analyses to insure the adequacy of the design and constructability.

a. Exploration and Testing. Exploration along the proposed alignment shall be made to evaluate the foundations conditions. Exploration includes drilling test holes at appropriate intervals to obtain disturbed and undisturbed samples for classification tests, moisture content, density, and consistency. Representative samples should be obtained for shear and consolidation testing when warranted.

b. Stability. Stability analyses for rubble-mound structures should be performed in accordance with EM 1110-2-1902. Selected strength parameters should be based on laboratory tests representing actual and anticipated field conditions. Both the during construction and long-term stability conditions should be analyzed. As a minimum, longitudinal and transverse sections should be evaluated. In addition, analyses should be performed for special conditions such as temporary construction slopes, anticipated scour, and the location and potential migrations of adjacent channels.

c. Settlement. Total and potential differential settlement, both longitudinal and transverse as well as during and after construction of the breakwater or jetty structure, should be determined in accordance with EM 1110-2-1904. These values should be used in determining the need for crest overbuild as well as the stress and stability of structural elements sensitive to the movement such as the prefabricated armor unit and caisson structures.

d. Foundation Protection. Migration of fines from the foundation may cause settlement and other damage to a structure. This damage can be mitigated by a bedding layer that conforms to the filter requirements. Scour of the foundation can also cause failure of the toe. The zone of scour and the location of stability failure areas should be clearly identified to determine the extent of toe protection.

(1) Rubble aprons. Experience indicates that the use of rubble aprons to protect the foundation of vertical or almost vertical walls from undermining is advisable, except for depths well below twice the maximum wave

height or on seabeds of very hard and durable material, such as ledge rock. If wave action causes a volume of water to spill over the breakwater, the effect of this water is equivalent to the action of water discharging over a dam; and protection of the foundation on the harbor side is as important as on the sea side or lake side.

(2) Bedding layers. When large stone is placed directly on a sand bottom at depths insufficient to avoid wave action and currents on the bottom, it will settle into the sand until it reaches a depth below which the sand will not be disturbed by the currents. Even if the amount of stone deposited is sufficient to provide protection after settlement, the settlement will probably be irregular, resulting in an irregular and unsightly structure which is more susceptible to wave damage. To prevent waves and currents from removing foundation materials through the voids in stone structures or protective aprons and destroying their support, all stone and other materials having large voids should be placed on a bedding layer of smaller stone. This material should be sufficiently graded to prevent the removal of the foundation material through the blanket or the loss of blanket material into the voids of the cover stone.

e. Low Bearing Capacity Foundations. When the bottom material is soft and does not have sufficient bearing capacity to support the structure, a pile foundation may be needed. In preparing a foundation of this type the piles can be driven to a minimum depth by use of a water jet, but below this depth they should be driven by hammer without the use of a water jet until the piles will safely support the design load. After foundation piles have been driven, stone should be deposited over the entire area and, after settlement, leveled to the elevation of the pile tops. If necessary, bottom material between the upper portion of the piles can be removed before the stone is deposited. As an alternative, pile-anchored floating breakwaters may prove feasible, provided that design wave periods are relatively short.

f. Construction Materials. After the stone size has been determined and the type of structure selected, the materials and their sources and availability should be investigated. In the case of rock the quantity, quality, density, durability, and grading should be determined. Producer service records are helpful in selecting sources of construction materials.

2-8. Ice Conditions. Open-coast harbors built seaward from the shoreline and protected by massive breakwaters are seldom affected to any great extent by ice. Longshore currents or prevailing winds will cause ice transport, and the breakwater design should be such that this ice will not be trapped. If ice is trapped it should be easily flushed out by tides and currents. Breakwaters designed to withstand large waves are usually not damaged by ice, except walls, railings, lights, or other structures on top of the breakwater can be severely damaged when ice rides over the breakwater. Ice forces may be the controlling design load for breakwaters built in mild wave environments. The crushing strength of ice is about 400 pounds per square inch, and thrust per linear foot is about 58,000 pounds per foot of depth. Structures subject to impacts from floating ice should be capable of resisting 10 to 12 tons per square foot on the area exposed to the greatest thickness of floating ice. Detailed procedures for quantifying ice loadings are contained in EM 1110-2-1612.

a. Ice Forces on Piles. Lightly loaded piles can be lifted when ice that is frozen to the pile is subject to vertical movement by tides and seiche. Long-period oscillations allow the sheet ice to freeze at the pile, and buoyancy forces acting on the entire sheet may lift the pile before the ice fails. The second half of the oscillation does not return the pile to its original position since it takes a higher force to drive the pile. Figure 2-2 shows a typical pile driven narrow-end down. A fiberglass, PVC, or plastic vertical-sided sleeve (as shown on the right side of the figure) provides a surface along which the ice can slip. The sleeve should extend below the ice level at lower low water levels. Floes of broken ice can subject piles to abrasion and impact damage.

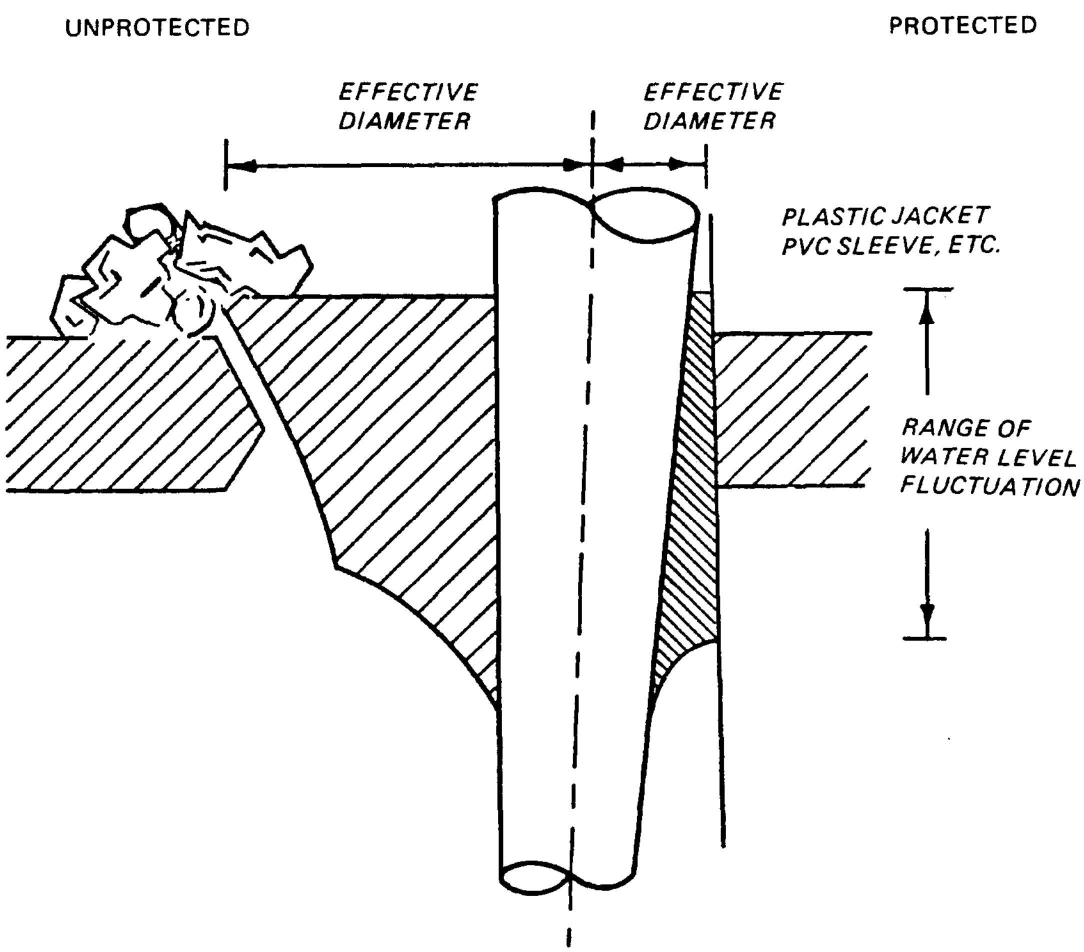


Figure 2-2. Typical pile showing protection and nonprotection from ice

b. Ice Forces on Rubble-Mound Structures. Smaller armor stone and concrete armor units are subject to lifting when ice that is frozen to them is moved vertically by tides and seiche. However, because of the original random orientation of these units, small vertical or horizontal position changes normally have no significant effect on stability. Individual armor units may also incur abrasive or impact damage from broken ice floes.

c. Ice Forces on Floating Breakwaters. Floating breakwaters are subject to the same lifting, abrasive, and impact forces described in a and b above. In many instances, floating structures are only used seasonally and are placed in a protective dry-dock during winter months if ice loadings are possible; however, evaluation of ice loadings merit careful attention since they may prove to be the controlling design loads.

2-9. Shoreline Changes.

a. General. Knowledge of the natural growth or the recession of the shoreline and of the offshore hydrography is needed to predict the impact of a project. If the project creates adverse impacts such as accretion or erosion, suitable mitigation measures such as sand bypassing or beach protection structures may be required.

b. Evaluation Methods. Historic changes can be determined from old charts or photographs. The NOS survey sheets are a good source of information since they show actual soundings of most coastal areas dating to the early 1800's. Care must be taken when comparing old survey data to assure that horizontal and vertical controls are corrected to a common reference. Old photographs can give approximate indications of changes; however, quantitative comparisons are difficult because water levels (tide, lake fluctuations, or river stages) are usually unknown. Surveys taken after completion of the project should always be made at the same time of the year to avoid inclusion of seasonal changes.

2-10. Prior Projects and Their Effects. Previous projects of similar type and scope often provide valuable information. While a new breakwater or jetty project is in the design stage a comprehensive review of similar projects may yield guidance to solutions of unanswered design questions. Most importantly, this review may stimulate consideration and analysis of problem areas that would have otherwise been overlooked.

2-11. Baseline Surveys. Physical and environmental surveys of the project site are needed during the preconstruction design phase. Bathymetric and hydraulic survey data are also to be used for model construction and verification. The following surveys are usually needed:

a. Bathymetric and topographic.

b. Beach profile.

c. Waves: Height, period, direction, and duration (spectral distribution of wave energy may be needed).

d. Currents: Velocity, direction, and duration.

e. Sediment: Suspended and bedload.

f. Beach composition.

g. Foundation conditions.

h. Wind: Speed, direction, and duration.

i. Ice: Frequency, duration, and thickness.

j. Biological population: Type, density distribution, and migration.

k. Water quality.

Dredged material water-disposal sites will usually need data from the a, d, j, and k baseline surveys.

2-12. Design Life, Degree of Protection, and Design Conditions. The project design life and the degree of protection are required before design conditions can be selected. The economic design life of most breakwaters and jetties is 50 years. The degree of protection during the 50-year period should be selected by an optimization process of frequency of damages (both to the structure and the area it protected) when waves exceed the design wave. Figure 2-3 and item 3 show the statistical relationship of project life, chance of event exceedance, and return period of event. Figure 2-3 shows that a wave with a height equal to or greater than the 100-year return period wave has a 39 percent chance of being exceeded during a 50-year project life. Chance of event exceedance may also be determined from figure 2-4. Design optimization is discussed in Chapter 10.

2-13. Dredging and Disposal. Dredging may be required to gain access to the site, for entrenching toe materials, or for various other reasons. When dredging is necessary a study should be conducted to determine volume of dredging, transport method, and the short- and long-term disposal impacts. Beneficial uses of dredged material should also be considered. Guidance on dredging disposal and beneficial uses of dredged material can be found in EM 1110-2-5025.

a. Dredges. The type of dredging equipment required should be suited to the wave environment and water depths characteristic of the project site. Rock or coral excavations normally require blasting with material removal by a clam shell shovel. Soft materials can be expediently handled with pipeline dredges.

| PERCENT CHANCE OF GETTING ONE OR MORE SUCH OR BIGGER WAVES IN THIS MANY YEARS | | | | | WAVE RETURN PERIOD, YEARS |
|---|---|---|---|---|---|
| ONE HUNDRED YEARS | FIFTY YEARS | TWENTY-FIVE YEARS | TEN YEARS | ANY ONE YEAR | |
| | | | | 50 | 2 |
| | | | | 40 | |
| | | | | 30 | |
| | | | | 25 | |
| | | | | 20 | 5 |
| | | 99 | 80 | 15 | |
| | 99.9 | 94 | 65 | 10 | 10 |
| | 90.5 | 71 | 40 | 5 | 20 |
| 86 | 61 | 40 | 18 | 2 | 50 |
| 64 | 39 | 22 | 9.6 | 1 | 100 |
| 40 | 22 | 12 | 5 | 0.5 | 200 |
| 18 | 9.5 | 5 | 2 | 0.2 | 500 |
| 10 | 4.8 | 2.5 | 1 | 0.1 | 1000 |
| 5 | 2.3 | 1.2 | 0.5 | 0.05 | 2000 |
| 2 | 1.0 | 0.5 | 0.2 | 0.02 | 5000 |
| 1 | 0.5 | 0.25 | 0.1 | 0.01 | 10,000 |

Figure 2-3. Relationship of project life, chance of event exceedance, and return period of event

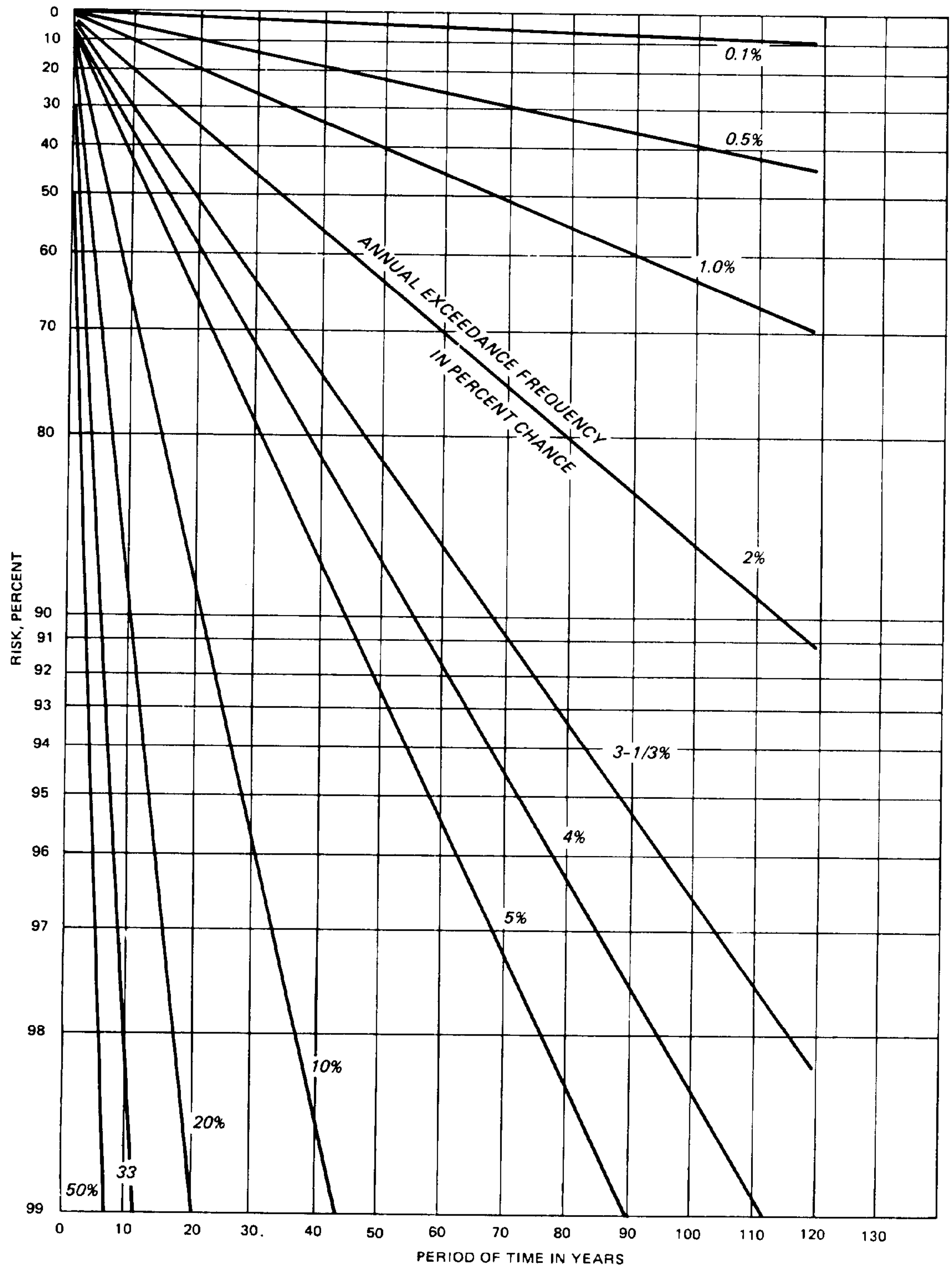


Figure 2-4. Risk of one or more events exceeding a given annual exceedance frequency within a period of time

b. Disposal Methods. Dredged material can be disposed of in open water or behind confinement dikes. Contaminated material is generally disposed of behind containment dikes, with careful monitoring of return water quality.

2-14. Seismic Design. Since failure of most breakwater and jetty projects as a result of an earthquake will not result in catastrophic consequences, these structures are generally not designed with seismic considerations. For projects located in high seismic risk zones, however, the geotechnical evaluation for these projects should at least consider the potential impact of seismic damage. If the cost to repair the seismic damage is considerable, as compared with the replacement cost, a detailed seismic evaluation may be warranted. The decision to design for seismic considerations should be decided on a case-by-case basis.

2-15. Environmental Impact. Environmental impacts generally fall into three categories: (a) dredging and disposal, (b) water quality impact of the project during normal operation, and (c) induced erosion or accretion. Both short-term construction and long-term impacts should be considered. Chapter 8 discusses environmental impacts.

2-16. Model Tests. Hydraulic model tests provide valuable input to breakwater and jetty design. Normally, proposed structure sections are optimized with a two-dimensional (2-d) stability model. The stability model results are used as input to final selection of structure details such as armor weight, crown height and width, and toe dimensions. The complexity of the breakwater head will determine whether three-dimensional (3-d), angular-wave attack stability tests are needed.

2-17. Operation and Maintenance (O&M). A comprehensive plan of how the project will be operated and maintained is required. This plan is presented in support of the operation and maintenance (O&M) costs. The following elements are normally included in the O&M plan.

a. Predicted Project Costs and Physical Changes. Include the post-construction prediction of physical changes and anticipated O&M costs.

b. Surveillance Plan. Describe the type and frequency of post-construction surveys. These could be hydrographic, aerial photos, beach profile, tide and wave records, and stability. The plan covers minimum monitoring of project performance to verify safety and efficiency. Cost information is for O&M budgetary purposes.

c. Analysis of Survey Data. Comparative studies of the survey data are required. These comparative studies verify design information such as rates of erosion, shoaling, and jetty deterioration.

d. Periodic Inspections and Project Performance Assessment. Present a tentative periodic inspection schedule. Inspections include a site assessment and a comparison of survey data with project changes predicted during the design effort.